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# Evaluation of Five Pendimethalin-Based Pre-Emergence Herbicides Formulations for Long-lasting Weed Infestation Control in Broadcasted Sesame (*Sesamum indicum* L.)

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Weed infestation is among the major constrains restricting the sesame (*Sesame indicum* L.) yield. The current study employed field trials conducted at Agricultural Research Station, Itay EL-Baroud, Behera Governorate, Egypt in 2021 and 2022, to examine the response of broad-leaved and grassy weeds to five pendimethalin-based herbicides at two formulations, concentrate suspension (CS) and emulsifiable concentrate (EC) and different recommended rates. The study comprised 6 treatments, including five various formulations pre-emergence herbicides namely, Stomp Extra 45.5% CS, Most 45.5% CS, X Closf 40% EC, Bendifex 30% EC and Garostob 50% EC. Additionally, hand weeding was performed twice at 21 and 35 days after sowing (DAS) compared with the unweeded control. for weed control biomass of broad-leaved and grassy weeds. The results revealed significantly no fresh biomass recorded for all broad-leaved weeds during the season 2021 with the application of Garostob 50 % EC in treated plots compared to other treatments. The positive influence of Garostob 50% EC on suppressing the fresh weight of broad-leaved weeds extended during the 2022 season. However, it failed to completely control *Hyoscyamus muticus* L., *Hibiscus trionum* L. *and Solanum nigrum* L. during the season 2022. Application of Bendifex 30% EC proved also significant ($p < 0.05$) reduction in the weed biomass (g $m^{-2} \pm$ SD) of *S. nigrum* (0.0 ± 0.0), *Ammi majus* L. (11.8 ± 0.7) and *Euphorbia hirta* Ait. (0.0 ± 0.0) when compared to other treatments. Application of Stomp Extra 45.5% CS did not show significant difference and showed equal efficacy to Garostob 50% EC in decreasing the weed biomass of *Cyperus longus* L., *Echinochloa colonum* L. and *Polypogon monospeliensis* L. over the cropping seasons 2021and 2022. Pendimethalin formulation herbicides significantly had a substantial influence on yield and yield characteristics, together with oil and protein contents (%) in both seasons 2021 and 2022. In this regard, Stomp Extra 45.5% CS resulted in the greatest grain yield/fed in the cropping seasons 2021and 2022 with values reached 765.5 and 698.3 kg, respectively. Application of Stomp Extra 45.5% CS resulted also in a significant increase in oil and protein percentages in season 2021 (53.4 and 25.9%) and in season 2022 (55.43 and 24.87%).
**Keywords**: Biomass, formulation, fresh weight, growth, herbicides, pendimethalin, sesame, weeds, yield.

## INTRODUCTION

The cultivation of sesame (*Sesame indicum* L.) traces its roots back to the Harappa Valley in the Indian subcontinent around 5,500 BC, making it one of the ancient crops recognized by humankind (Bedigian and Harlan, 1986). The versatile nature of sesame makes it valuable as a raw material for the manufacturing of confectionery and bakery products. Additionally, its oil finds applications in various industries such as carbon paper, perfume, soap, edible vegetable oils, and pharmaceuticals (Yol *et al*., 2010). Sesame is grown on more than five million acres (20,000 km2) in numerous parts

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of the world. Of the 22 nations that produce the most sesame worldwide, six are in Asia, thirteen are in Africa, and three are in Latin America (Central and South America). The top three producers are China, India, and Myanmar, whereas the bottom three are Benin, Bangladesh, Paraguay, and Mali. Based on FAO figures, the combined production of these major sesame-producing countries accounts for 92.6% of global sesame production (UNSD, 2017; FAOSTAT, 2022). With almost 40% of the world's sesame acreage and 27% of its production, India continues to be the world's leading producer of sesame. Asia grows 70% of the world's sesame crop, whereas Africa grows 26% of it (Zerihun, 2012).

Production of sesame is hampered in terms of profitability and productivity by a number of major issues. Low yields, pest and disease susceptibility, variable maturity, the absence of cultivars that are adaptable, capsule shattering, poor fertilizer response, high branching, and a low harvest index are among the main problems (Lukurugu *et al.,* 2023). One of the main obstacles to the production of sesame is capsule cracking, which results in substantial seed loss (up to 50%) during harvest and lower yields (Qureshi *et al*., 2022). The most widely used technique is still manual harvesting, although it takes a lot of time and labor, which raises production costs and lowers profitability (Day, 2000). Precise seed placement in the soil poses a significant challenge when planting sesame due to its small seed size (Langham *et al.,* 2007b). Seed should neither be buried too deeply, preventing the cotyledons from reaching the surface, nor placed too shallowly, risking moisture loss. When the cotyledons appear, they are small than other crops and exhibit slower growth. This slow development is further influenced by sesame's drought resistance, which causes the plant to allocate a substantial portion of its photosynthetic resources to increasing root mass, enabling its swift penetration of the soil in search of moisture (Langham *et al.,* 2007a).

Weed infestation is among the major factors the limit the sesame production, where the seedling growth is slow during the initial four weeks rendering it a weak competitor during the early stages of crop growth (Bennett and Condé, 2003; Babiker *et al.,* 2014; Ismail *et al*., 2024). The growth of sesame is adversely affected by several types of weeds, including monocotyledons, dicotyledons, and perennials, during the seedling period. Consequently, this leads to a reduction in production per unit area (Adewale, 2019). The presence of weeds significantly hampers sesame crop productivity due to its slow seedling growth within the initial four weeks, rendering it a weak competitor during the early crop progression phases (Eid *et al.,* 2015; Lukurugu *et al.,* 2023). Although weeds can be controlled using cultural, biological, and chemical means, labor problem shortage is getting more acute by the day, and it will no longer be practicable or economical either to continue with traditional weed management practices (Tataridas *et al.,* 2022; Singh *et al.,* 2022; Kumar *et al.,* 2023)**.** Herbicides alone, however, are incapable of providing total weed control due to their selective killing. Their usage can be improved by combining it with manual weeding or hoeing (Nainwal *et al.,* 2010). The invasion of numerous annual grasses and broadleaf weeds poses a substantial threat to this crop, resulting in significant losses. The detrimental impact of weed competition on yields ranged between 50% and 75% in oilseed crops (Bhadauria *et al.,* 2012)**.** The method of manual weeding is frequently employed by farmers; however, the paucity of farm labor and the high expense associated with weeding operations make it impractical to carry out weeding activities.

When compared to other weed management alternatives, herbicide treatment provides the highest weed control effectiveness, the best selectivity, the lowest cost and efficient in terms of time and labor conservation when compared to alternative methods (Ahmed *et al.,* 2008; Soliman *et al.,* 2015). At the early stage of growth, pendimethalin, a selective pre-emergence herbicide, has demonstrated promising effectiveness in suppressing barnyard grass and various other weed species (Smith, 2004). Pendimethalin exhibits root and coleoptile absorption in emerging weeds, and to some extent, leaf absorption as well. It serves as a herbicide in winter cereals, functioning as both a pre-emergence and early-post and post-emergence treatment until weed BBCH 13. Pre-emergence and early post-emergence treatments have proven to be effective in managing silky bent grass (Grichar *et al.,* 2012; Menegat *et al.,* 2014). Furthermore, Sagarka (2014), found out that the application of pendimethalin at rates of 450 or 750 g/ha, and subsequently conducting hand hoeing after one month, demonstrated remarkable effectiveness in reducing weed biomass and promoting higher sesame seed yield.

The variations in formulations of a given herbicide have been observed to significantly influence both its effectiveness in controlling weeds and the degree of damage it may cause to crop plants (Grey and Webster, 2013). Therefore, the aim of this study was to inspect the comparative efficacy of certain pre-emergence pendimethalin-based formulations in comparison to hand hoeing in reducing and controlling weed infestation of broad-leaved and grassy weeds along with determining their indirect effect on sesame productivity and oil content.

## MATERIALS AND METHODS

***Plant Materials and Sowing*****:** Sesame grains (*Sesamum indicum* L.) Giza 32 cv. were obtained from Administration of Seeds, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Giza, Egypt. In both seasons, sesame seeds were hand planted in hills 25 cm apart and ridges 70 cm, 20 and 25 May, respectively, at the recommended rate of 4kg fed$^{-1}$. The chemical and physical

**Table 1. Some physical and chemical properties of the experimental soil.**

| Site | EC (dS/m) | pH | Cations (meq/L) | | | | Anions (meq/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $Ca^{++}$ | $Mg^{++}$ | $Na^{+}$ | $K^{+}$ | $CO_3^{--}$ | $HCO_3^{-}$ | $Cl^{-}$ | $SO_4^{-}$ |
| Mean | 2.26 | 7.73 | 5.4 | 4.15 | 12.2 | 15.0 | 0.0 | 3.15 | 11.5 | 7.2 |

| Site | SAR (%) | $CaCO_3$ (%) | Particle distribution (%) | | | Texture |
|---|---|---|---|---|---|---|
| | | | Clay | Silt | Sand | |
| Mean | 5.44 | 4.81 | 51.5 | 15.5 | 33.5 | Clay |

**Table 2. The herbicides used in this study and their recommended rates**

| Trade name | Common name | Recommended Rate $fed^{-1}$/ 200L water | Time of application | Source |
|---|---|---|---|---|
| Stomp Extra 45.5% CS | Pendimethalin | 1500ml | Pre- emergence | Basf, Co |
| Most 45.5% CS | | 1700ml | (After sowing and | Agerokim , Co |
| X Closf 40% EC | | 1500 ml | before irrigation) | Tabarek lelesmadah ,Co. |
| Bendifex 30% EC | | 1250 ml | | Sanabel Agro Egypt, Co |
| Garostob 50% EC | | 1700ml | | Bridge trad, Co |

CS = Concentrate Suspension, EC = Emulsifiable Concentrate.

attributes of soil (Table 1) of the experimental field were analyzed at the department of Soils and Water, Faculty of Agriculture, Alexandria University, Alexandria, Egypt. All plants were fertilized with organic manure (20 m3/fed), and received calcium super phosphate15% $P_2O_5$ once at 200 kg/fed. during planting. Fertilization with nitrogen was applied at 50 kg /fed. before the first irrigation and potassium was added at a rate of 48 kg K2O/fed at 60 days after sowing.

***Experimental Site and Layout*:** Experiments were carried out during 2021 and 2022 seasons at Agricultural Research Station, Itay EL-Baroud, Behera Governorate, Egypt. The study employed a randomized complete block design (RCBD) with three replications to conduct the experiments. Each replicate represents a plot of 21 $m^{-2}$ (2.1 m width and 10 m length), representing 1/200 fed. Herbicides include certain pendimethalin formulations of pre-emergence herbicides namely Stomp Extra 45.5% CS, Most 45.5% CS, X Closf 40% EC, Bendifex 30% EC and Garostob 50% EC) as well as hand hoeing (two-times at 21 and 35 days after sowing (DAS)) in relative to unweeded control (Table 2). The herbicides were applied at recommended rates using a 5-liter knapsack sprayer (Gloria hoppy No.299 TS) at 200-liter $fed^{-1}$ (Ismail *et al*., 2024). At 60 days after planting, the central row weeds were collected, sorted out and weighed as fresh weight (g $m^{-2}$) of broad-leaved as well as narrow-leaved in each treatment.

***Evaluation of weed control treatments*:** Nine weeks after sowing in both growing seasons 2021 and 2022, weeds of the middle row in each plot of all treatments were collected and sorted counted, identified following Hassanein *et al.* (2000) and their fresh weights were recorded as g $m^{-2}$.

The following criteria were calculated: Weed biomass =average (fresh) weight of each weed (g $m^{-2}$).

***Yield Evaluation*:** Morphological traits and yield parameters were measured as reported by Ismail *et al.* (2024). At harvest, in October in both seasons, respectively, 10 plants were randomly selected from each plot and subjected to air-drying for 4 days and the following agronomic traits were measured: At harvesting, the following data were reported:

1. Plant height (cm).
2. No. of branches/ Plant.
3. No. of capsules/ Plant.
4. No. of grains/ capsules
5. 1000 grains weight (g)
6. Grain yield (Kg/ fed)
7. Stalk yield (kg/fed) (Straw yield)
8. Harvest index (%)

***Determination of oil and protein content in sesame seeds*:** Oil percentage in seeds was assessed following the techniques of AOAC (1980) employing Soxhlet apparatus. Crude protein percentage in seeds was assessed utilizing Kjeldahl apparatus as nitrogen percentage following the methods of AOAC (1980). To determine the protein percentage, the nitrogen percentage was multiplied by 6.25 conversion factor.

***Statistical Analysis*:** Prior to analysis, the fresh biomass data of weeds underwent a logarithmic transformation (log[X + 1]) to achieve a normalized distribution (Dey and Pandit, 2020). The data were analyzed by analysis of variance one-way ANOVA, and means were separated with Fisher's protected least significant difference (LSD) test at a significance level of $p \leq 0.05$ using CoStat computer software, version 2.6 CoStat program (2002). Data were expressed as the mean ± standard deviation (SD).

## RESULTS AND DISCUSSION

***Weed Survey*:** The surveyed experimental site showed the presence of eight dominant broad-leaved and narrow weeds from five different families (Table 3).

***Effect of Pendimethalin Formulations on the Individual Broad-leaved Weeds (BLW):*** The findings shown in Tables 4 and 5 demonstrate that all examined herbicides and hand

**Table 3. The broad-leaf and narrow leaved weeds prevailed in the experimental sesame field during the seasons of 2021 and 2022.**

| English name | Scientific name | Family name | Type of weeds |
|---|---|---|---|
| Bladder hibiscus | *Hibiscus trionum* L. | Malvaceae | Annual broad-leaved weeds |
| Sun spurge | *Euphorbia hirta* Ait. | Euphorbiaceae | |
| Bishops weed | *Ammi majus* L. | Umbelliferae | |
| Black Nightshade | *Solanum nigrum* L | Solanaceae | Perennial broad-leaved weeds |
| White henbane | *Hyoscyamus muticus* L. | Solanaceae | |
| Nutsedge | *Cyperus longus* L. | Cyperaceae | Perennial Narrow-leaved weeds |
| Jungle Rice | *Echinochloa colonum* L. | Gramineae | Annual Narrow-leaved weeds |
| Beard grass | *Polypogon monospeliensis* L. | Gramineae | |

**Table 4. Impact of various formulations of pendimethalin on biomass of broad-leaved weeds in sesame field during 2021cropping season.**

| Treatments | Weed Biomass (g m$^{-2}$) ± SD | | | | |
|---|---|---|---|---|---|
| | ***Hy. muticus*** | ***H. trionum*** | ***S. nigrum*** | ***A. majus*** | ***E. hirta*** |
| Stomp Extra 45.5% CS | 46.9 ± 3.4$^{c}$ | 119.0 ± 6.6$^{d}$ | 22.5 ± 2.4$^{bc}$ | 25.9 ± 1.5$^{d}$ | 32.3 ± 1.9$^{cd}$ |
| Most 45.5% CS | 191.7 ± 9.1$^{b}$ | 187.8 ± 10.4$^{bc}$ | 32.3 ± 2.6$^{bc}$ | 43.1 ± 2.5$^{b}$ | 64.9 ± 3.9$^{de}$ |
| X Closf 40% ES | 45.9 ± 4.2$^{c}$ | 196.1 ± 10.8$^{bc}$ | 24.9 ± 3.5$^{bc}$ | 17.3 ± 1.0$^{e}$ | 81.3 ± 4.8$^{bc}$ |
| Bendifex 30% EC | 187.5 ± 19.7$^{b}$ | 160.0 ± 8.8$^{cd}$ | 0.0 ± 0.0$^{c}$ | 11.8 ± 0.7f | 0.0 ± 0.0$^{e}$ |
| Garostob 50 % EC | 0.0 ± 0.0$^{c}$ | 0.0 ± 0.0$^{e}$ | 0.0 ± 0.0$^{c}$ | 0.0 ± 0.0$^{g}$ | 0.0 ± 0.0$^{e}$ |
| Hand-hoeing | 213.4 ± 24.0$^{b}$ | 213.3 ± 11.8$^{b}$ | 42.8 ± 4.0$^{b}$ | 35.7 ± 2.1$^{c}$ | 112.5 ± 6.7$^{b}$ |
| Umweeded Control | 2187.9 ± 170.9$^{a}$ | 1116.5 ± 61.7$^{a}$ | 726.7 ± 48.2$^{a}$ | 113.5 ±$^{a}$ | 971.3 ± 57.9$^{a}$ |
| L.S.D at 5 % | 134.1 | 44.9 | 38.6 | | 45.7 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

**Table 5. Effect of different formulations of pendimethalin on biomass of broad-leaved weeds in sesame field during 2022 cropping season.**

| Treatments | Weed Biomass (g m$^{-2}$) ± SD | | | | |
|---|---|---|---|---|---|
| | ***Hy. muticus*** | ***H. trionum*** | ***S. nigrum*** | ***A. majus*** | ***E. hirta*** |
| Stomp Extra 45.5% CS | 138.8 ± 9.0$^{d}$ | 179.0 ± 9.3$^{cd}$ | 268.3 ± 15.4$^{b}$ | 0.0 ± 0.0$^{c}$ | 25.9 ± 1.3$^{a}$ |
| Most 45.5%CS | 185.8 ± 12.1$^{cd}$ | 197.8 ± 10.3$^{cd}$ | 283.8 ± 16.3$^{b}$ | 7.5 ± 0.3$^{bc}$ | 43.3 ± 2.3$^{d}$ |
| X Closf 40% ES | 239.0 ± 12.4$^{c}$ | 153.8 ± 8.0$^{d}$ | 289.0 ± 16.6$^{b}$ | 6.3 ± 0.2$^{bc}$ | 62.0 ± 3.2$^{c}$ |
| Bendifex 30% EC | 187.9 ± 12.2$^{cd}$ | 229.0 ± 11.9$^{c}$ | 276.3 ± 15.9$^{b}$ | 0.0 ± 0.0$^{c}$ | 0.0 ± 0.0$^{f}$ |
| Garostob 50 % EC | 141.8 ± 9.2$^{d}$ | 152.5 ± 7.9$^{d}$ | 151.3 ± 8.7$^{c}$ | 0.0 ± 0.0$^{c}$ | 0.0 ± 0.0$^{f}$ |
| Hand-hoeing | 668.3 ± 35.8$^{b}$ | 375.0 ± 19.5$^{b}$ | 308.0 ± 17.7$^{b}$ | 13.8 ± 0.5$^{b}$ | 90.0 ± 4.7$^{b}$ |
| Umweeded check | 2323.7 ± 92.6$^{a}$ | 1828.0 ± 95.2$^{a}$ | 1375.0 ± 79.1$^{a}$ | 362.5 ±13.3$^{a}$ | 287.5 ±15.0$^{a}$ |
| L.S.D at 5 % | 67.2 | 69.7 | 10.8 | 53.1 | 11.6 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

hoeing treatments significantly ($p$ < 0.05) decreased the biomass (fresh weight) of broad-leaved weeds, including *Hibiscus trionum* L., *Euphorbia hirta* Ait., *Ammi majus* L., *Hyoscyamus muticus* L and *Solanum nigrum* L. The significant effectiveness of each herbicidal treatment, namely Garostob 50 % EC, Stomp Extra 45.5% CS, and Bendifex 30% EC in controlling broad-leaved weeds throughout the growing seasons of 2020 and 2021, was readily apparent. The results revealed significantly no fresh biomass recorded for all broad-leaved weeds during the season 2021 with the application of Garostob 50 % EC treated plots compared to other treatments (Table 4).

Moreover, the application of Garostob 50 % EC exhibited a persistent positive impact on diminishing the weed FW of broad-leaved weeds during the season 2022 (Table 5). But it failed to completely control *Hy. muticus, H. trionum and S. nigrum* during the season 2022. Further, application of Bendifex 30% EC also proved significantly ($p$ < 0.05) superiority in reducing the FW g /m$^2$ ± SD of weeds *S. nigrum* (0.0 ± 0.0), *A. majus* (11.8 ± 0.7) and *E. hirta* (0.0 ± 0.0) to other treatments (Table 4). Application of Bendifex 30% EC

also exhibited a complete reduction to the FW g /$m^2$ ± SD of weeds *A. majus* (0.0 ± 0.0) and *E. hirta* (0.0 ± 0.0) when compared to other treated weeds and herbicides (Table 5). No significant difference was noticed in the FW g /$m^2$ ± SD of weeds between the two formulations Most 45.5% CS and X Closf 40% EC in both seasons. Alternatively, twice hand weeding at 21 and 35 days after sowing (DAS) demonstrated the statistically lowest treatment in diminishing the FW g /$m^2$ ± SD of broad-leaved weeds during 2021 and 2022 seasons (Table 4, 5). Contrary to our results, Kebede *et al*. (2016), demonstrated that the treatment involving hand weeding twice at 20 and 40 DAS exhibited notable superiority in reducing the dry weight of broad-leaved weeds. Moreover, the results of current study revealed also that broad-leaved weeds in weedy check plots exhibited a considerably higher FW g /$m^2$ at 65 DAS of all other treatments. This was attributed to the possibility that weed seeds were inadvertently transported to the surficial soil during the first-hand weeding. This unintentional placement may have provided weeds with an advantage, including improved soil aeration and favorable growth factors, leading to their accelerated growth and progression. As a result, there was a higher accumulation of fresher biomass among the weeds. These findings agree with Khan and Saghir (1990) and Hafeezullah (2000) who documented a notably increased weed dry weight within weedy check compared to the treated plots. The differences in the relative FW of weeds could be attributed to varying levels of effectiveness of the treatments on different weed types found within the experimental field.

***Effect of Pendimethalin Formulations on the Individual Grassy-leaved Weeds (GLW*): Data presented in Tables 6 demonstrate that all pendimethalin formulation namely Stomp Extra 45.5% CS, Most 45.5% CS, X Closf 40% EC, Bendifex 30% EC and Garostob50% EC along with hand hoeing twice significantly ($p < 0.05$) decreased the fresh weight of total narrow-leaved weeds in both growing seasons in comparison with weedy control. According to statistical analysis all pendimethalin formulations exhibited unsatisfactory control of *Cyperus rotundus*., *Echinochloa colonum*., *Polypogon monospeliensis*, except for the Stomp Extra 45.5% CS and Garostob 50% EC formulation. Application of Stomp Extra 45.5% CS did not show significant difference from and Garostob 50% EC in decreasing the weed biomass of *C. longus*, *E. colonum* and *P. monospeliensis* over the cropping seasons 2021and 2022. Similarly, Yadav (2004) also documented that applying

**Table 6. Influence of different formulations of pendimethalin on biomass of narrow-leaved weeds in sesame field during 2021cropping season.**

| Treatments | Weed Biomass (g $m^{-2}$) ± SD | | |
|---|---|---|---|
| | ***C. longus*** | ***E. colonum*** | ***P. monospeliensis*** |
| Stomp Extra 45.5% CS | 98.3 ± 7.4$^{d}$ | 87.3 ± 6.5$^{e}$ | 54.2 ± 4.1$^{c}$ |
| Most 45.5%CS | 165.4 ± 12.4$^{bc}$ | 188.7 ± 14.1$^{bcd}$ | 112.4 ± 8.4$^{bc}$ |
| X Closf 40% ES | 123.6 ± 9.3$^{cd}$ | 167.9 ± 12.6$^{cd}$ | 145.3 ± 10.9$^{bc}$ |
| Bendifex 30% EC | 176.5 ± 13.2$^{b}$ | 210.2 ± 15.7$^{bc}$ | 198.4 ± 14.8$^{b}$ |
| Garostob 50 % EC | 105.1 ± 7.9$^{d}$ | 95.4 ± 7.1$^{de}$ | 84.3 ± 6.3$^{c}$ |
| Hand-hoeing | 169.5 ± 12.7$^{b}$ | 274.3 ± 20.5$^{b}$ | 132.4 ± 9.9$^{bc}$ |
| Unweeded check | 871.7 ± 65.2$^{d}$ | 1786.5 ± 133.7$^{a}$ | 1932.5 ± 144.6$^{a}$ |
| L.S.D at 5 % | 45.4 | 100.1 | 111.9 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

**Table 7. Effect** of **different formulations of pendimethalin on biomass of narrow-leaved weeds in sesame field during 2022 cropping season**.

| Treatments | Weed Biomass (g $m^{-2}$) ± SD | | |
|---|---|---|---|
| | ***C. longus*** | ***E. colonum*** | ***P. monospeliensis*** |
| Stomp Extra 45.5% CS | 115.8 ± 6.9$^{c}$ | 0.0 ± 0.0$^{d}$ | 37.5 ± 2.9$^{cd}$ |
| Most 45.5%CS | 167.0 ± 10.0$^{bc}$ | 45.7 ± 3.3$^{cd}$ | 85.3 ± 6.7$^{bc}$ |
| X Closf 40% ES | 139.5 ± 8.3$^{c}$ | 87.1 ± 6.3$^{bc}$ | 97.3 ± 7.6$^{bc}$ |
| Bendifex 30% EC | 183.8 ± 11.0$^{bc}$ | 112.9 ± 8.2$^{b}$ | 0.0 ± 0.0$^{d}$ |
| Garostob 50 % EC | 140.0 ± 8.4$^{c}$ | 0.0 ± 0.0$^{d}$ | 0.0 ± 0.0$^{d}$ |
| Hand-hoeing | 233.3 ± 13.9$^{b}$ | 175.3 ± 12.7$^{b}$ | 127.3 ± 1.0$^{b}$ |
| Unweeded check | 1558.0 ± 93.0$^{a}$ | 978.8 ± 70.8$^{a}$ | 1289.3 ± 100.7$^{a}$ |
| L.S.D at 5 % | 68.7 | 67.4 | 79.7 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

pendimethalin (0.5 kg/ha) during the pre-emergence stage at 40 DAS induced a significant ($p < 0.05$) decline in weed fresh weight and greatest weed control efficacy. Alternatively, no significant ($p < 0.05$) differences were noticed among the rest of pendimethalin formulations in terms of reducing FW biomass of narrow-leaved weeds when applied at their relative doses in both seasons.

Moreover, the results of current study revealed also that narrow -leaved weeds in weedy control plots revealed higher FW g /m$^2$ ± SD at 65 DAS of all other treatments. Comparable findings were documented by Belfry *et al.,* (2016), who found that the weedy check exhibited the greatest fresh and dried weed biomass (414.08 and 82.81 gm.m$^{-2}$) whereas the pendimethalin treatment had the lowest (169.50 and 33.90 g m$^{-2}$). Our findings could be explained as the application of pre-emergence herbicide pendimethalin inhibited the weeds at germination phase, which is supported by those previously published (Mruthul *et al.,* 2015; Sujithra *et al.,* 2018). Our experimental results align with those of previous studies (Sharma *et al*., 2000; Sharma *et al.,* 2004) who documented successful control of grass weeds utilizing metolachlor and pendimethalin. The relative weed density provides insight into the distribution and relative abundance of different weed categories across various treatment methods, but it may not indicate the specific treatment's capacity to eliminate a specific weed category (Kebede *et al.,* 2016). The tested herbicides varied in their herbicidal activity against the prevailed narrow-leaved weeds which belong to different species and therefore, may be possess differential susceptibility to the tested herbicide formulations. Also, the activities of the tested herbicides were varied in both seasons and this may be attributed to different climatic conditions. Furthermore, these outcomes may be related to the inhibitory impact of herbicidal treatments on weed development, as well as the kind of formulations, adjuvant ingredients in pesticide formulations as previously demonstrated (Imoloame *et al.,* 2011; Aruna *et al.,* 2020).

***Impact of weed control interventions on sesame crop yield and yield component*:** Pendimethalin formulation herbicides significantly had a substantial influence on yield and yield-related parameters of sesame, in both seasons 2021 (Table 8) and 2022 (Table 9). In this regard, Garostob and Stomp Extra had the greatest effect. On the other side, hand hoeing treatment resulted in increment in yield with value reached 570.2 and 578.9 K.g. fed$^{-1}$ during both seasons 2021 and 2022, respectively, whereas the corresponding grain values

**Table 8. Impact of various formulations of pendimethalin and hand-hoeing on yield attributes and yield of sesame crop at harvest season 2021.**

| Treattments | Plant height (cm) | No. of branches/ plant | No. of capsules/ plant | No. of grains/ capsules | Weight of 1000 grains (g) | Grain yield (kg/fed) | Stalk yield (kg/fed) | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|
| Stomp Extra 45.5% CS | 171.2±13.7$^a$ | 10.7±1.7$^a$ | 53.7±3.9$^a$ | 58.7±4.1$^a$ | 46.5±10.4$^a$ | 765.5±75.4$^a$ | 2454.0±174.7$^a$ | 31.2±2.2$^a$ |
| Most 45.5%CS | 141.1±11.3$^c$ | 8.3±1.2$^{ab}$ | 37.7±4.6$^d$ | 48.0±4.1$^{cd}$ | 37.7±7.9$^{bc}$ | 634.4±66.6$^c$ | 2120.0±242.3$^b$ | 29.9±5.1$^a$ |
| X Closf 40% ES | 147.5±14.8$^{bc}$ | 6.0±1.4$^{bc}$ | 42.3±2.9$^c$ | 52.3±5.7$^{bc}$ | 42.3±8.4$^{abc}$ | 695.8±73.0$^b$ | 2250.0±110.2$^{ab}$ | 30.9±3.7$^a$ |
| Bendifex 30% EC | 152.0±10.8$^b$ | 8.3±1.2$^{ab}$ | 46.3±4.2$^b$ | 53.3±3.9$^b$ | 43.1±7.1$^{ab}$ | 712.3±74.8$^b$ | 2356.0±167.7$^{ab}$ | 30.2±4.3$^a$ |
| Garostob 50 % EC | 165.0±12.9$^a$ | 8.7±0.9$^a$ | 47.7±2.5$^b$ | 58.7±5.0$^a$ | 46.9±8.1$^a$ | 744.4±78.1$^a$ | 2381.0±272.2$^{ab}$ | 31.3±3.8$^{ab}$ |
| Hand-hoeing | 143.7±10.2$^{bc}$ | 6.0±0.8$^{bc}$ | 44.0±2.2$^c$ | 45.0±4.1$^d$ | 36.7±3.6$^c$ | 570.2±59.8$^d$ | 2145.0±245.2$^{ab}$ | 26.6±3.8$^{ab}$ |
| Umweeded check | 102.1±19.9$^d$ | 5.0±1.6$^c$ | 26.3±2.9$^e$ | 34.7±2.9$^e$ | 30.7±6.1$^d$ | 323.6±53.6$^e$ | 1380.0±157.7$^c$ | 23.5±2.8$^b$ |
| L.S.D at 5 % | 9.7 | 2.5 | 2.1 | 4.4 | 5.8 | 32.0 | 308.8 | 4.8 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

**Table 9. Impact of various formulations of pendimethalin and hand-hoeing on yield attributes and yield of sesame crop at harvest season 2022.**

| Treattments | Plant height (cm) | No. of branches/ plant | No. of capsules/ plant | No. of grains/ capsules | Weight of 1000 grains (g) | Grain yield (kg/fed) | Stalk yield (kg/fed) | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|
| Stomp Extra 45.5% CS | 189.2±13.0$^a$ | 12.3±2.1$^a$ | 57.7±11.9$^a$ | 53.3±7.9$^a$ | 43.9±10.6$^a$ | 698.3±33.0$^a$ | 2319.0±138.0$^a$ | 30.1±2.0$^a$ |
| Most 45.5%CS | 146.7±10.0$^e$ | 8.7±1.7$^{cd}$ | 42.0±4.9$^{cd}$ | 41.0±5.9$^b$ | 36.7±6.2$^c$ | 620.4±29.3$^c$ | 2190.0±184.6$^{ab}$ | 28.3±3.9$^a$ |
| X Closf 40% ES | 154.6±8.8$^d$ | 7.3±1.2$^e$ | 39.3±7.4$^{de}$ | 42.3±5.2$^b$ | 39.1±6.6$^{bc}$ | 612.3±28.9$^c$ | 2115.0±109.6$^b$ | 29.0±1.9$^a$ |
| Bendifex 30% EC | 160.3±11.0$^c$ | 9.3±1.2$^{bc}$ | 48.3±8.8$^{bc}$ | 48.0±5.7$^{ab}$ | 39.2±8.3$^{bc}$ | 589.2±27.8$^d$ | 2089.7±109.1$^b$ | 27.8±2.5$^a$ |
| Garostob 50 % EC | 173.6±9.9$^b$ | 10.3±1.2$^b$ | 52.7±10.4$^{ab}$ | 51.3±6.6$^a$ | 41.8±7.0$^{ab}$ | 654.1±30.9$^b$ | 2235.0±190.3$^{ab}$ | 29.3±3.1$^a$ |
| Hand-hoeing | 147.9±10.1$^e$ | 7.7±1.7$^{de}$ | 43.0±4.3$^{cd}$ | 42.0±5.7$^b$ | 36.2±6.1$^c$ | 578.9±27.4$^e$ | 2064.7±122.2$^b$ | 27.6±4.2$^a$ |
| Umweeded check | 112.5±6.4$^f$ | 5.3±1.2$^f$ | 31.7±4.1$^e$ | 31.7±4.0$^c$ | 28.5±5.5$^d$ | 413.5±19.5$^f$ | 1880.0±112.7$^c$ | 22.0±2.5$^b$ |
| L.S.D at 5 % | 4.4 | 1.0 | 8.2 | 7.7 | 4.2d | 9.2 | 175.2 | 4.1 |

For a significance level of P ≤ 0.05, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

with untreated control were 323.6 and 413.5 kg fed$^{-1}$. Similar trend was observed with both weight of grains and yield Kg. plot$^{-1}$ in both seasons. On the contrary, in most cases the lowest agronomic traits were recorded with Most 45.5%CS, X Closf 40% EC, and Bendifex 30% EC in both seasons.

Overall, the results showed that all herbicidal treatments, along with hand hoeing, significantly improved the agronomic traits of sesame crop, particularly grain yield, when compared to the unweeded control, with no significant differences in weight of 1000grain (gm.) in the 1$^{st}$ season. In pendimethalin formulation treated plots, sesame exhibited injury levels of up to 88 %. However, the surviving plants managed to recover from the damage and produce a modest yield. According to Grichar *et al*. (2018), sesame plants possess the ability to offset the effects of open spaces and suboptimal growth through developing supplementary branches with capsules. Nevertheless, branching can only serve as compensation for smaller gaps (30 cm). Broader gaps, on the other hand, not only result in reduced yields, but also allow sunlight to penetrate the canopy, providing favorable conditions for the development and growth of weeds during the later stages of the growing season.

In both the 2021 and 2022 seasons, a greater number of branches per plant had occurred when Garostob and Stomp Extra were applied during the pre-emergence stage, surpassing all other weed control methods. Also, the application of both formulation herbicides followed by hand hoeing resulted in a higher number of capsules per plant. Additionally, the weed control treatments had an impact on the number of seeds per capsule and the weight of 1000 seeds. The number of productive capsules per plant under improved technology were 53, 37, 42, 46 and 48 as against local control, 57.2, 42.1, 39.2, 48.3 and 52.3 during the year 2021 and 2022, respectively.

Higher seed yield was recorded after application of Garostob and Stomp Extra (765.5 and 744.4 kg fed$^{-1}$) in season (2021) and (654.1 and 698.3 kg fed$^{-1}$) in season 2022, compared to unweeded control (323.6 and 413.5 kg fed$^{-1}$) (Tables 8 and 9). This can potentially be attributed to the maintenance of weed-free conditions up to a critical threshold, leading to higher weed control effectiveness. As a result, growth and yield were improved. According to Imoloame *et al*. (2011), an increase in herbicide rate induced a decrease in plant height regardless of the specific herbicide used. In our study, the number of capsules per plant and the grain yield of sesame were considerably impacted by pre-emergence herbicides in both years, as well as when considering the combined means.

The results clearly indicated that yield parameters improved by different weed control treatments can be ascribed to effective weed management and weed competition. This improvement in yield could be attributed to the impact of pre and early post emergence herbicides that mitigated the crop-weed competition contributed significantly to improved weed control, leading to reduced weed density and dry weight. These findings align with the findings of El-Metwally (2016). As a result, moisture nutrients, and light were made more readily available for crop growth. Comparable findings have been documented by Mruthul *et al*. (2015) and Yadav (2004). The lowest yield parameters exhibited by the unweeded control can be owed to intense competition from weeds throughout the crop growth stages.

The increase in weight of grain (Kg. fed$^{-1}$) in relative to the unweeded control can be due to adequate weed suppression, leading to increased availability of plant nutrients to the sesame crop. According to Gupta and Kushwah (2016), the weed control practices had significant impacts on the yield-related characteristics of sesame crop. Treatment involving two hand weeding carried out at 20 and 40 DAS exhibited the greatest plant height, number of branches/ plants, number of leaves/plants, number of capsules/plants, grains/capsule, 1,000- grain weight (g), plant dry weight (g), grain yield/plant (g), stalk yield (kg/ha), grain yield (kg/ha), and harvest index (%). Significant variations were noticed in the impact of weed control practices and cow dung manure rates on grain yield. The treatment involving hand weeding twice att 3 and 6 weeks after sowing exhibited the greatest grain yield, followed by

**Table 10. Effect of pendimethalin formulation herbicidal treatments on oil and protein content in sesame seeds during seasons, 2021 and 2022 seasons.**

| Treatments | Season 2021 | | Season 2022 | |
|---|---|---|---|---|
| | **Oil %** | **Protein %** | **Oil %** | **Protein %** |
| Stomp Extra 45.5% CS | 53.4 ± 3.2$^{a}$ | 25.9 ± 1.3$^{a}$ | 55.43 ± 3.6$^{a}$ | 24.87 ± 1.4$^{a}$ |
| Most 45.5%CS | 50.2 ± 3.0$^{c}$ | 21.2 ± 1.1$^{e}$ | 50.76 ± 3.3$^{c}$ | 23.11 ± 1.3$^{b}$ |
| X Closf 40% ES | 47.4 ± 2.8$^{e}$ | 21.6 ± 1.1$^{d}$ | 50.65 ± 3.3$^{c}$ | 20.31 ± 1.2$^{d}$ |
| Bendifex 30% EC | 49.2 ± 2.9$^{d}$ | 20.5 ± 1.1$^{f}$ | 52.45 ± 3.4$^{bc}$ | 21.54 ± 1.2$^{cd}$ |
| Garostob 50 % EC | 53.7 ± 3.2$^{a}$ | 23.3 ± 1.2$^{b}$ | 54.12 ± 3.5$^{a}$ | 23.97 ± 1.4$^{ab}$ |
| Hand-hoeing | 52.0 ± 3.1$^{b}$ | 22.1 ± 1.2$^{c}$ | 52.76 ± 3.4$^{ab}$ | 22.58 ± 1.3$^{bc}$ |
| Umweeded check | 45.6 ± 2.7$^{f}$ | 20.4 ± 1.1$^{f}$ | 48.93 ± 3.2$^{c}$ | 20.21 ± 1.2$^{d}$ |
| L.S.D at 5 % | 0.40 | 0.21 | 2.98 | 1.47 |

For a significance level of $P \leq 0.05$, distinct lowercase letters signify significant differences among means within each column as inferred from Fisher's protected LSD test.

Pendimethalin at 2.0 kg a.i. ha$^{-1}$, outperforming the other treatments. These findings in accordance with those of Olorunmaiye (2010).

***Effect of different herbicides and hand-hoeing on oil and protein content in sesame seeds*:** The data obtained from Table 10 indicated that none of the tested herbicides caused any decrease of oil or protein content in sesame seeds in both seasons. Instead, all herbicides caused a significant increase of oil content and protein content in the two succeeding seasons except in the season 2021, since Garostob and Stomp Extra gave slight increase of % of oil content. However, X Closf and Bendifex by had a little impact on protein content in second season (2022). For pendimethalin, concerning oil and protein percentages in the seeds the findings were not fully in agreement with Fayed *et al.*, (1992) who documented that pendimethalin exhibited an insignificant influence on oil and protein percentages in peanut seeds. In our study, yields of oil and protein component were significantly increased as a resultant in the seed yield. The herbicides X Closf and Bendifex had also a positive effect on both oil and protein percentages in seeds compared to the unweeded control. These results agree with Kumar *et al.*, (2004), and with Deuber *et al.*, (1978), and in case of oil and protein yields the results agree with Fayed *et al.*, (1992) who specified that yields of oil and protein component were significantly increased by weed control treatments as a resultant in the seed yield.

For hand-weeding, hand-hoeing once exhibited a substantial impact on both oil and protein percentages compared to the control. Our findings are in agreement with those of Fayed *et al.*, (1983), but resulted in oil and protein yields in kg/fed higher than the control but still low effective than the other weed control treatments including hand-weeding twice. Hand-hoeing twice showed the same trend for the first season 2021, but in the second season resulted in significant increase on both oil and protein percentages compared with the control, which were contrary with Fayed *et al.*, (1983) who indicated that mechanical weed control (hoeing) exhibited insignificant impact on both oil and protein percentages in either soybean or peanut seeds.

***Heatmap Clustering Analysis*:** Heatmap clustering analysis was carried out to identify the associations between different pendimethalin formulations in comparison to hand-hoeing based on the investigated parameters over the cropping seasons 2021and 2022 (Figure 1a, b). The parameters were placed on the Y-axis, whereas the treatments were placed on X-axis (Figure 1). The herbicidal treatments were grouped into two major clusters A and B (Figure 1a, b). The unweeded check clustered in a single cluster. The results of the heatmap clustering indicated a distinct variation in measured parameters in response to pendimethalin formulations in comparison to hand-hoeing and unwedded control (Figure 1a, b). The parameters were clustered into major clusters 1 and 2, the later was subdivided into two sub-clusters, which contained most of the parameters. It is clear from the heatmap analysis that Stomp Extra 45.5% CS had the greatest effect on all parameters especially those related to growth and yield attributes. However, the concentration of the active ingredient pendimethalin in Stomp Extra is lower and at a different formulation (45.5% CS) than Garostob 50 % EC. The results indicated that the application of Stomp Extra 45.5% CS exhibited a considerable influence on the majority of investigated parameters of sesame in response for pre-emergence treatment.

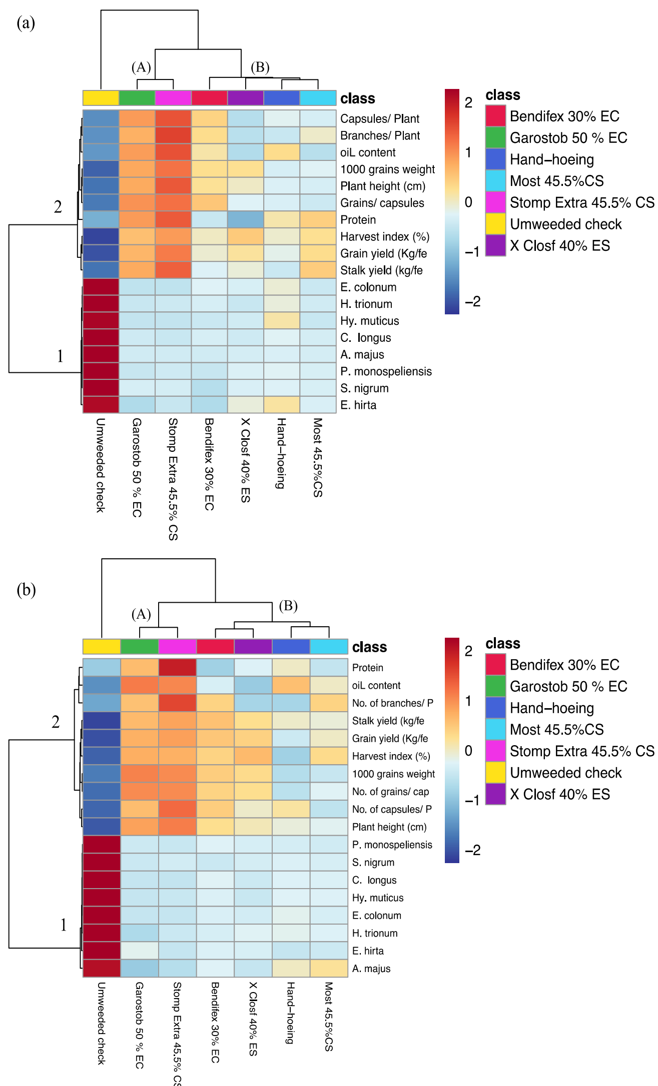


**Figure 1. Heatmap hierarchical cluster analysis based on measured parameters in season 2021(A) and 2022 (B). Parameters were placed on the Y-axis, whereas the pendimethalin formulations were placed on X-axis. Colors indicate high (red) and low (blue) associations between different treatments and investigated parameters**.

**Table 11. Economic costs of using different herbicide formulations compared to hand during 2021 and 2022 seasons.**

| Treatments | Rat fed$^{-1}$ | Cost (L.E/fed) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2021 Season | | | | | | 2022 Season | | |
| | | Herbicide cost | Labor & atomizer cost | Total cost | Grain yield (kg/fed) | Net benefit | Gross income | Grain yield (kg/fed) | Net benefit | Gross income |
| Stomp Extra 45.5% CS | 1500 ml | 1132 | 200 (1 laborer) | 1332 | 765.5 | 26792.5 | 28124.5 | 698.3 | 24440.5 | 25772.5 |
| Most 45.5%CS | 1700 ml | 1100 | 200 | 1300 | 634.4 | 22204.0 | 23504.0 | 620.4 | 21714.0 | 23014.0 |
| X Closf 40% ES | 1500 ml | 1249 | 200 | 1449 | 695.8 | 24353.0 | 25802.0 | 612.3 | 21430.5 | 22879.5 |
| Bendifex 30% EC | 1250 ml | 950 | 200 | 1150 | 712.3 | 24930.5 | 26080.5 | 589.2 | 20622.0 | 21772.0 |
| Garostob 50 % EC | 1700 ml | 1100 | 200 | 1300 | 744.4 | 26054.0 | 27354.0 | 654.1 | 22893.5 | 24193.5 |
| Hand-hoeing | Twice | 00 | 3200 (16 laborer) | 3200 | 570.2 | 19957.0 | 23157.0 | 578.9 | 20261.5 | 23461.5 |
| Umweeded check | | 00 | 0 | 0 | 323.6 | 11326.0 | 11326.0 | 413.5 | 14472.5 | 14472.5 |

-Hand hoeing twice cost: 16 laborers fed.$^{-1}$ for 2 hand hoeing at 200 (L.E.) laborer$^{-1}$ day$^{-1}$, herbicide application cost: 1 laborer$^{-1}$fed.$^{-1}$ at 200 L.E. laborer$^{-1}$ day$^{-1}$, atomizer cost for herbicide spraying of fed.

-Market price of weight of grain yield Kg fed$^{-1}$. 35 L.E. for Kg). Gross income = grain yield (Kg fed$^{-1}$)× market price (35 L.E. for Kg), Net benefit = gross income - total weeding cost.

***Economic analysis of weed control methods***: Data listed in Table 11 show the total weeding costs, gross income and net benefits of the tested weed control treatments that in valued in the selected herbicide application methods in sesame experimental field during both seasons 2021and 2022. Such data indicated that unweeded check recorded the lowest net benefit values during the two growing seasons which were 11326 and 14472.5 Egyptian Pound (L.E), respectively. On the other hand, the highest net benefit values were achieved with Stomp Extra and Garostob herbicides, while hand hoeing twice during the two growing seasons recorded the lowest net benefit values comparing unweeded check. Furthermore**,** Stomp Extr cost was 26792.5 and 24440.5 L.E, while hand hoeing twice cost was 19957 and 20261.5 L.E. in the two studied seasons 2021and 2022, respectively.

General speaking, herbicides application revealed the highest net benefit values during the two studied seasons, whereas the two hand hoeing application and unweeded control recorded the lowest net benefit values. These findings are in corroboration with those of many published studies (Al-Mamun *et al*., 2011; Singh *et al*., 2016). Also, our findings are in agreement with Mandal *et al*. (2011), who reported that chemical methods of weed control proved more economical in terms of net return and benefit cost ratio. On the other side, Hamill and Zhang (1995) and Hamill *et al*. (1995) concluded that hand weeding is very laborious, time consuming and expensive. In addition, during the peak period, the availability of labor is also becoming a serious problem by time. However, herbicides are used successfully for weed control in crops for rapid effect, easier to application and low cost involvement in comparison to the traditional methods of hand weeding. Perez-Ruiz *et al*. (2013) found that herbicide treated plots were better in economic return as compared to the mulches and hand weeding practices.

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***SDG's addressed*:** Zero Hunger,Responsible Consumption and Production,Life on Land,Climate Action,Decent Work and Economic Growth.

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